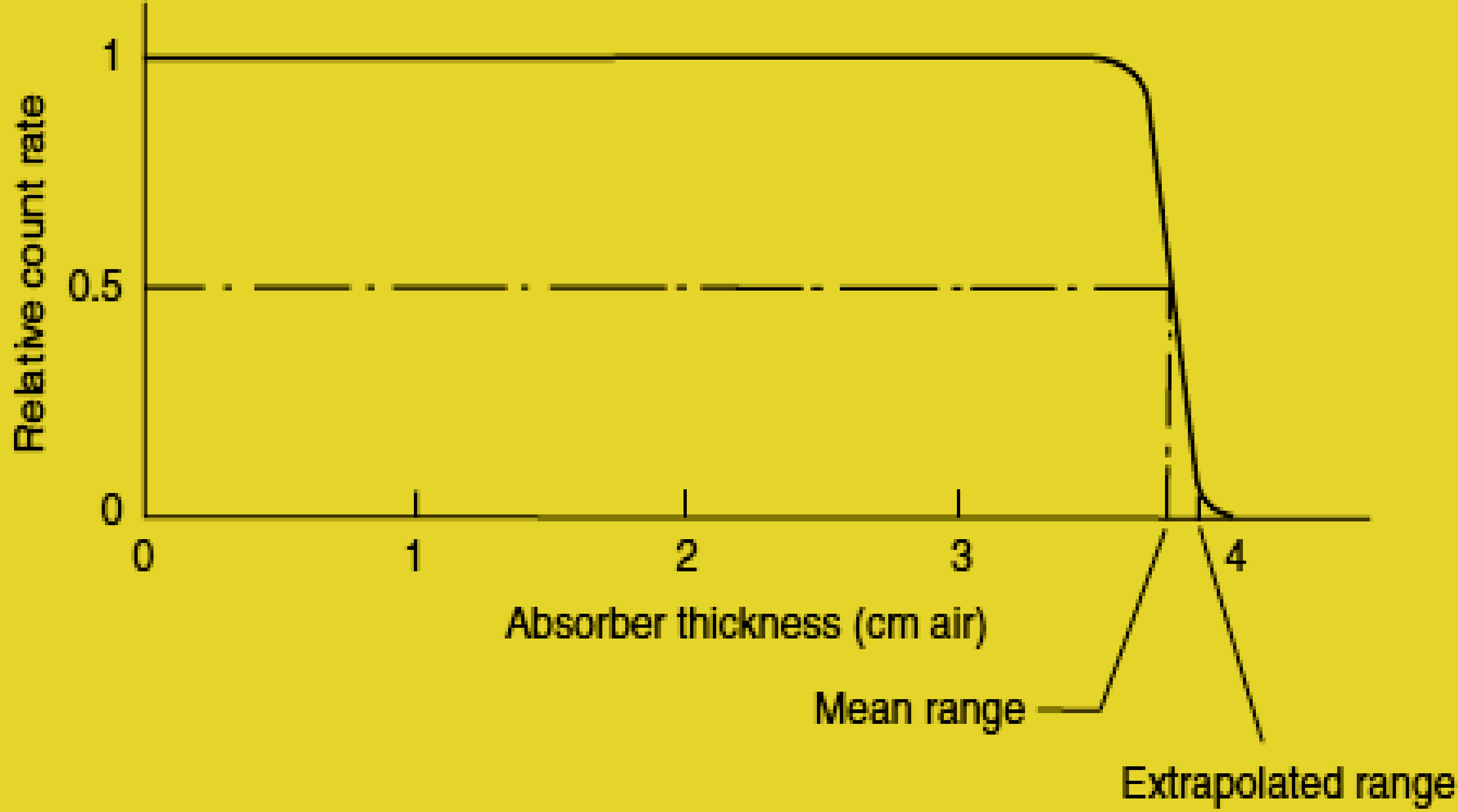
1.2 Alpha Rays

1.2.1 Energy Relationship

Alpha rays are the least penetrating of the radiations. In air, even the most energetic alphas from radioactive substances travel only several centimeters, while in tissue, the range of alpha radiation is measured in micron ($1\mu = 10^{-4}$cm). The term range, in the case of alpha particles, may have two different definitions: mean range and extrapolated range. The difference between these two ranges can be seen in alpha particle absorption curve, Fig 2-1.



Figure(2-1):Alpha particle absorption curve.

An alpha particle absorption curve is flat because alpha radiation is essentially monoenergetic. Increasing thickness of absorption serves merely to reduce the energy of the alphas that pass through the absorbers; the number of alpha is not reduced until the approximate range is reached. At this point, there is a sharp decrease in the number of alphas that pass through the absorber.

Near the very end of the curve, absorption rate decreases due to straggling, or the combined effects of the statistical distribution of the “ average” energy loss per ion and the scattering by the absorber nuclei. The mean range is the range most accurately determined, and corresponds to the range of the “average” alpha particle. The extrapolated range is obtained by extrapolating the absorption curve to zero alpha particles transmitted.

Air is the most commonly used absorbing medium for specifying range–energy relationships of alpha particles. The range (in cm) of air, R_a, *at* $0^\circ C$ *and 760 mm Hg* pressure of alphas whose energy E *is between 2 MeV and 8 MeV is closely approximated* (within 10%) by the following empirically determined equation:

$$R_a = 0.332E^{3/2} \qquad (2\text{-}1)$$

The range of alpha particles in any other medium whose atomic mass number is *A* and whose density is *ρ may be computed from the following relationship:*

$$R_a \times \rho_a \times (A_m)^{0.5} = R_m \times \rho_m \times (A_a)^{0.5}, \quad (2\text{-}2)$$

where

R_a and R_m = range in air and tissue (cm),

A_a and A_m = atomic mass number of air and the medium, and

ρ_a and ρ_m =density of air and the medium(g/cm^3)

EXAMPLE 2-1

What thickness of Al foil, density 2.7 g/cm^3, is required to stop the alpha particles from ^{210}Po?

Solution

The energy of the ^{210}Po alpha particle is 5.3 MeV. From Eq. (2-1), the range of the alpha particle in air is

$$\boldsymbol{R = 0.322 \times (5.3)^{3/2} = 3.93 \text{ cm.}}$$

Substituting

$$\boldsymbol{R_a = 3.93 \text{ cm}, \quad A_m = 27,}$$

$$\boldsymbol{A_a = (0.2 \times 16 + 0.8 \times 14),}$$

$\rho_m = 2.7\ g/cm^3$, *and*
$\rho_a = 1.293 \times 10^{-3}\ g/cm^3$ *into Eq. (2-2),then*

$$R_{\mathrm{m}} = \frac{R_{\mathrm{a}} \times \rho_{\mathrm{a}} \times (A_{\mathrm{m}})^{0.5}}{\rho_{\mathrm{m}} \times (A_{\mathrm{a}})^{0.5}} = \frac{3.93\,\mathrm{cm} \times 1.293 \times 10^{-3}\,\mathrm{g/cm^3} \times (27)^{0.5}}{2.7\,\mathrm{g/cm^3} \times (0.2 \times 16 + 0.8 \times 14)^{0.5}}$$
$$= 2.58 \times 10^{-3}\,\mathrm{cm}.$$

The range of the 5.3 MeV-alpha, in units of density thickness, from Eq.

$$t_{\mathrm{d}} = t_{\mathrm{d}} \times \rho = 2.58 \times 10^{-3}\,\mathrm{cm} \times 2.7\,\frac{\mathrm{g}}{\mathrm{cm^3}} = 7 \times 10^{-3}\,\frac{\mathrm{g}}{\mathrm{cm^2}}.$$

Because the effective atomic composition of tissue is not very much different from that of air, the following relationship may be used to calculate the range of alpha particles in tissue:

$$R_a \times \rho_a = R_t \times \rho_t, \qquad (2\text{-}3)$$

where

R_a and R_t = range in air and tissue and
ρ_a and ρ_t = density of air and tissue.

EXAMPLE 2-2

What is the range in tissue of a ^{210}Po alpha particle? ***R_a= 3.93 cm***

$$R_t = \frac{R_a \times \rho_a}{\rho_t} = \frac{3.93\ \text{cm} \times 1.293 \times 10^{-3}\ \text{g/cm}^3}{1\ \frac{\text{g}}{\text{cm}^3}} = 5.1 \times 10^{-3}\ \text{cm}.$$

Energy Transfer

The major energy-loss mechanisms for alpha particles that are considered to be significant in health physics are collisions with the electrons in the absorbing medium.
These interactions result in electronic excitation and ionization of the absorber atoms.

In a collision between a heavy ionizing particle and an orbital electron in an absorbing medium, the energy transferred from the ionizing particle to the orbital electron is given by:

$$\Delta E = \frac{2\,(9 \times 10^9 \times Q \times q)^2}{m a^2 v^2}, \qquad (2\text{-}3)$$

where

Q = charge on the ionizing particle,

q = charge on the electron,

m = mass of the electron, and

a = closest distance of approach of the ionizing particle to the electron (called the *impact parameter*)

EXAMPLE 2-3

The first ionization potential, *φ, of the O_2 molecule = 12.06 eV. A 5.3-MeV alpha* particle from ^{210}Po passes the molecule at a distance of 0.2 °A from an outer electron

(a) How much energy does the alpha particle transfer to the electron?

(b) If this amount of energy exceeds the ionization potential, what is the kinetic energy of the ejected electron?

Solution

(a) Equation (2-3) will be used to calculate the transferred energy. First calculate v^2 *for substitution into Eq. (2-3). Relativity effects are trivial at* α of 5.3 MeV. Therefore ,one may use the Newtonian expression for kinetic energy,

$$E_k = \frac{1}{2}mv^2.$$

Solving for v^2, we have:

$$v^2 = \frac{2E_k}{m} = \frac{2 \times 5.3\ \text{MeV} \times 1.6 \times 10^{-13}\ \text{J/MeV}}{6.64424 \times 10^{-27}\ \text{kg}} = 2.55 \times 10^{14}\ \left(\frac{\text{m}}{\text{s}}\right)^2.$$

For an alpha particle, $Q = 2q$, therefore,

$$\Delta E_\alpha = \frac{2(9 \times 10^9 \times 2q^2)^2}{ma^2v^2} = \frac{2(81 \times 10^{18} \times 4q^4)}{ma^2v^2} = \frac{648 \times 10^{18} \times q^4}{ma^2v^2}.$$

Substit. the appropriate values for *m*, *a*, *and* v^2

$$\Delta E_{5.3\text{ MeV }\alpha} = \frac{648 \times 10^{18} \times \left(1.6 \times 10^{-19}\text{ C}\right)^4}{9.11 \times 10^{-31}\text{ kg} \times \left(2 \times 10^{-11}\text{ m}\right)^2 \times 2.55 \times 10^{14} \left(\frac{\text{m}^2}{\text{s}^2}\right)}$$

$$= 4.57 \times 10^{-18}\text{ J}.$$

Converting 4.57×10^{-18} J into electron volts, we have

$$\Delta E_{5.3\text{ MeV }\alpha} = \frac{4.57 \times 10^{-18}\text{ J}}{1.6 \times 10^{-19}\ \frac{\text{J}}{\text{eV}}} = 28.6\text{ eV}.$$

(b) $E_{\text{k,electron}} = \Delta E - \varphi = 28.6\,\text{eV} - 12.1\,\text{eV} = 16.5\,\text{eV}.$

In passing through air or soft tissue, an alpha particle loses, on average, 35.5 eV per ion pair that it creates. The specific ionization of an alpha particle is very high,on the order of tens of thousands of ion pairs per centimeter in air. This is due to its high electrical charge and relatively slow speed because of its great mass.

The slow speed allows a long interaction time between the electric fields of the alpha particle and an orbital electron of an atom in the medium through which the alpha particle passes, thus allowing sufficient energy transfer to ionize the atom with which it collides. As the alpha particle undergoes successive collisions and slows down, its specific ionization increases because the electric fields of the alpha particle and the electron have longer times to interact, and thus more energy can be transferred per collision.

This increasing ionization density leads to a maximum specific ionization
near the end of the alpha particle's range, as shown in Figure 2-2. This maximum is called the *Bragg peak*. An alpha particle loses energy at an increasing rate as it slows down until the Bragg peak is reached near the end of its range.

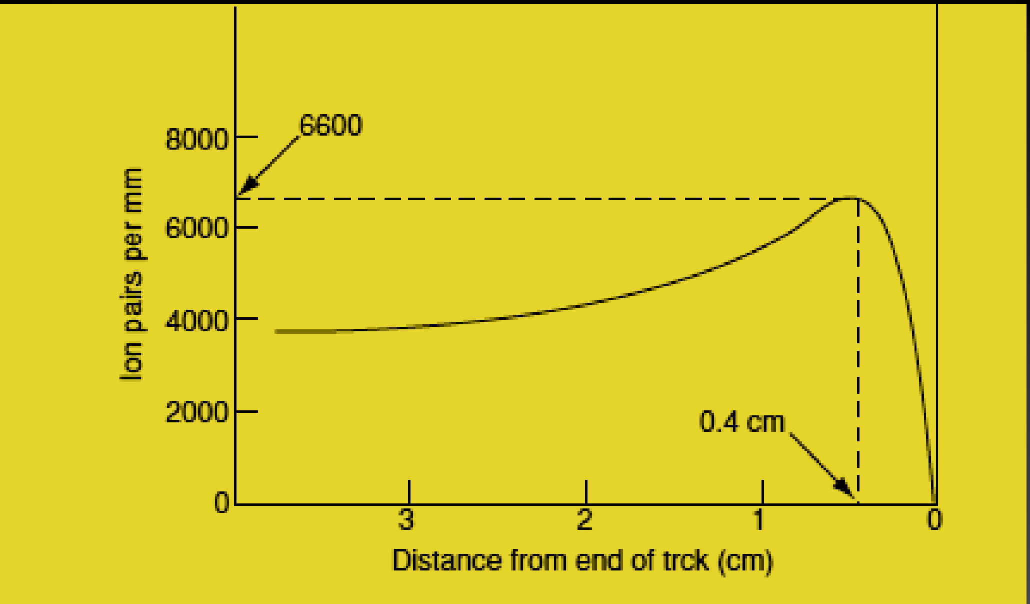


Figure 2-2. Specific ionization of a ^{210}Po alpha particle as a function of its remaining distance to the end of its range in standard air.

Because of its inertia due its heavy mass, an alpha particle undergoes very little deviation in a collision and therefore travels essentially in a straight line. Its average rate of energy loss may therefore be calculated as follows:

$$\frac{d\bar{E}}{dR} = \frac{\text{Kinetic energy}}{\text{Range}}. \qquad (2\text{-}3)$$

The mass stopping power of air for a ^{210}Po alpha particle is, according to Eq.(1-8), is given by

$$S(\text{air}) = \frac{d\bar{E}/dR}{\rho(\text{air})} = \frac{1.35\ \text{MeV/cm}}{1.293 \times 10^{-3}\ \text{g/cm}^3} = 1.04 \times 10^3\ \frac{\text{MeV}}{\text{g/cm}^2}.$$

The relative mass stopping power for α particles is defined in the same way as for βs Eq. [1-10]. In previous ex. R_t of a 5.3-MeV α particle is 5.1×10^{-3} cm. Its mean rate of energy loss in tissue,therefore, is

$$\frac{d\bar{E}}{dR}(\text{tissue}) = \frac{5.3\ \text{MeV}}{5.1 \times 10^{-3}\ \text{cm}} = 1.04 \times 10^{3}\ \frac{\text{MeV}}{\text{cm}},$$

and its mass stopping power, S, is

$$S(\text{tissue}) = \frac{d\bar{E}/dR}{\rho} = \frac{1.04 \times 10^{3}\ \text{MeV/cm}}{1\ \text{g/cm}^{3}} = 1.04 \times 10^{3}\ \frac{\text{MeV}}{\text{g/cm}^{2}}.$$

Using Eq. (1-10), calculate the relative stopping power of tissue, ρ_t, for 5.3MeV alpha particles

$$\rho_t = \frac{S_{\text{tissue}}}{S_{\text{air}}} = \frac{1.04 \times 10^{3}\ \dfrac{\text{MeV}}{\text{g/cm}^{2}}}{1.04 \times 10^{3}\ \dfrac{\text{MeV}}{\text{g/cm}^{2}}} = 1.$$